PHYSICS 11
LABORATORY MANUAL

Mr. K's Version

Sir Winston Churchill Secondary School
7055 Heather Street
Vancouver, B.C.
V6P 3P7

TABLE OF CONTENTS

Introduction
Significant Figures and
Uncertainty in Measurement………..3
Graphing…………………………… 5
Safety Instructions ………………… 9
Formal Lab Reports ……………….. 11
Data Table …………………………12

INVESTIGATIONS

Measurement
Traffic ………………………...13
The Density of a Solid Object …….. 14
Pendulum Lab………………………18

Kinematics
Uniform Motion…………………….20
Uniform Acceleration……………… 22
Acceleration Due to Gravity……..… 24
Using a webcam to analyze motion ...25
Spreadsheet Graphing……………….26
"World-in-Motion" – Acceleration
Due to Gravity………………………28

Dynamics
Force Mass, acceleration…………….29
Sliding Friction…………………..… 31
Elastic Forces……………………… 32

Energy
Power……………………………… 33
Specific Heat Capacity…………….. 34
The Efficiency of a Kettle…………..35

Momentum
"World-in-Motion – Impulse……….36
"World-in-Motion" – Conservation
of Momentum……………………… 37
Explosion……………………………38
Collisions on air track……………….39

Light and Optics
The Pinhole Camera……………….. 41
Multiple Images……………………. 42
Refraction………………………….. 44
Refraction of Light by Water……….45
Refraction of Light – Water into Air..46
Lenses ……………………………...47
The Astronomical Telescope………..48
The Diffraction of Light…………….49
Interference Patterns……………….. 50
Colour Theory………………………51

Relativity
Analyzing the Twin Paradox………. 52
Speed, Energy and Mass – The
Ultimate Speed…………..…………54

Nuclear Physics
Half-life……………………………. 57

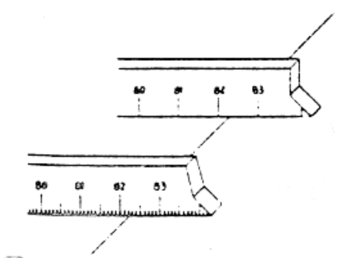
SIGNIFICANT FIGURES AND UNCERTAINTY IN MEASUREMENT

NUMBERS

All measured quantities consist of digits (numbers) and units. Two kinds of numbers are used in science - those that are counted or defined and those that are measured. The exact value of counted or defined numbers can be stated, but the exact value of a measured number cannot be known. For example, you can count the number of tables in this room, the number of fingers on your left hand and the amount of money in your pocket with absolute certainty. Defined numbers are exact relations, defined to be true and as a result are not subject to error. Examples of defined numbers are the number of seconds in an hour, the number of centimetres in a metre and the number of days in the year. Every measured number, no matter how carefully measured has some degree of uncertainty.

UNCERTAINTY IN MEASUREMENT

The uncertainty (margin of error) in a measurement depends on the precision of the measuring device and the skill of the person who uses it. Uncertainty in a measurement can be illustrated using the two different metre sticks shown in the diagram. The scale on the upper ruler is marked off in centimetres. Using this scale you can say that the length is between 82 and 83 cm. You can say further that it is closer to 82 cm than to 83 cm. .You can estimate it to be 82.2 cm. The lower scale has more subdivisions and has a greater precision because it is marked off in millimetres. Here, you can say that the length is definitely between 82.2 and 82.3 cm, and you can estimate it to be 82.25 cm. Note how both readings contain some digits that are exactly known, and one digit (the last one) that is estimated. The lower meter stick is more precise than the top one. The precision is indicated by the number of significant figures used.



SIGNIFICANT FIGURES

Significant figures are the digits in any measurement that are known with certainty plus one that is estimated and hence uncertain. Standard rules have been developed for writing and using significant figures, both in measurement and in values calculated from measurements.

Rule 1
In numbers that do not contain zeros, all the digits are significant.

Rule 2
All zeros between significant digits are significant.

Rule 3
Zeros to the left of the first nonzero digit that serve only to fix the position of the decimal point are not significant.

e.g. 0.0056 has 2 sig figs.   0.0987 has 3 sig figs.   0.000001 has 1 sig fig.

Rule 4
In a number with digits to the right of the decimal point, zeros to the right of the last non-zero digit are significant.

e.g. 43 has 2 sig figs. 43.0 has 3 sig figs.   43.00 has 4 sig figs.   0.00200 has 3 sig figs.

Rule 5

In a number that has no decimal point and that ends in one or more zeros (such as 2700), the zeros that end the number mayor may not be significant. To avoid confusion in this case, write the number in scientific notation.

e.g. 2.7×10^3 has 2 sig figs. 2.70×10^3 has 3 sig figs. 2.700×10^3 has 4 sig figs.

ROUNDING OFF

Calculators display eight or more digits. These digits are correct when calculating according to the rules of arithmetic, but they are not honest or correct when you are dealing with measured quantities. When you are dealing with measured values your answer must not state an unjustified number of significant figures. The following rules will help you in determining the correct number of digits in your answer.

Rule 1

If the first-digit to the right of the last significant figure is less than 5, that digit and all the digits that follow it are simply dropped.

e.g. 54.234 rounded off to 3 sig figs. becomes 54.2

Rule 2

If the first digit to be dropped is a digit greater than 5, the last retained digit is increased in value by one unit.

e.g. 54.351, 54.359, and 54.3598 rounded off to 3 sig figs all become 54.4

Rule 3

If the first digit to be dropped is a 5 not followed by any other digit, Or if it is a 5 followed only by zeros, an odd-even rule is applied. That is, round off to the nearest even digit.

e.g. 54.2500 rounded off to 3 sig figs becomes 54.2

54.3500 rounded off to 3 sig figs becomes 54.4

Rule 4 - Multiplying and Dividing

When multiplying and dividing, the answer should have the number of significant figures found in the number with the least number of significant figures.

e.g. $8.536 \times 0.47 = 4.01192$ (calculator answer)

but 0.47 has only 2 significant figures. Therefore, the answer must be rounded off to 4.0.

$3845 / 285.30 = 13.47704171$ (calculator answer)

but 3845 has only 4 significant figures. Therefore, must be rounded off to 13.48.

Rule 5 - Addition and Subtraction

For addition or subtraction, the answer should not have digits beyond the last digit position common to all numbers.

e.g. $15 + 18.8 + 34.6 = 67.4$ (calculator answer)

But, 15 is only accurate to the units place, therefore the answer must be rounded off to the units column.

REMEMBER: DO NOT GIVE ME ALL THE DIGITS ON YOUR CALCULATOR DISPLAY. ROUND OFF ACCORDING TO THE CORRECT NUMBER OF SIGNIFICANT DIGITS.

GRAPHING

A great deal of physics depends of deriving mathematical relationships from data. This can be done by plotting a graph and then calculating the equation for the best-fit line drawn through the data. The best-fit line is the line that is close to most of the data.

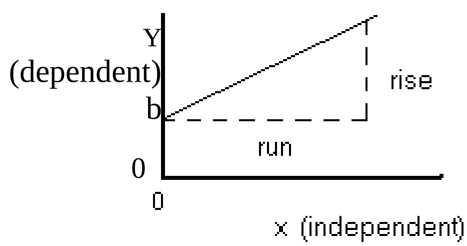
You have already dealt with calculating equations of lines in mathematics when you drew a graph and described it in the form of:

$$y = mx + b$$

This equation describes a direct relationship but can also be applied to other relationships with a little manipulation of the data. In this exercise you will also learn how to deal with exponential relationships, inverse relationships and some graphing conventions that are unique to science.

I Direct Relationships ($y \propto x$)

This is the graphing form that you are familiar with in math. In this relationship, when x doubles, y also doubles. When you are plotting data, the independent variable is usually plotted on the horizontal axis and the dependent variable is on the vertical axis.

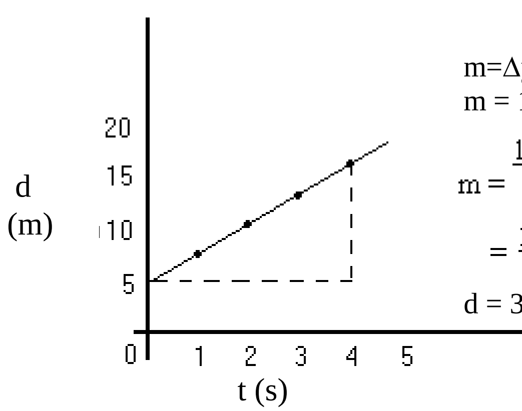


m is the slope (rise/run)
b is the y intercept

In physics we no longer label the axis as 'x' or 'y', but we name them after the physical quantities involved. These quantities also have units that must be included beside the axis.

A graph of the following data is shown below.

distance (m)	5.0	8.0	11	14	17
time (s)	0.0	1.0	2.0	3.0	4.0



$m = \Delta y / \Delta x$

m = 17m-5m/4.0s-0.0s

$m = \frac{12m}{4s}$

$= \frac{3m}{s}$

d = 3.0 m/s t + 5.0m

Hints for Successful Graphing

1.Every graph must have a title.
2.Name and label each axis with the appropriate quantities and units.
3.Mark the origin.
4.Use at least half a page for your graph.
5.Choose an axis scale that allows you to create a line at approximately 45° to each axis.
6.Draw a line that averages the uncertainties. Do not join the points, but draw a line that has the same number of points below the line as above the line.
7.Draw a large slope interval and measure the slope.
8.State the equation for the line and include units for the slope and intercept.

Practice Problems

1.Graph the following data and state an equation for each graph.
a)The circumferences and diameters of various circles were measured and recorded. Plot a graph of circumference vs. diameter. What is the relationship between circumference and diameter?

Circumference (cm)	3.1	6.3	9.4	12.6	15.7
Diameter (cm)	1.0	2.0	3.0	4.0	5.0

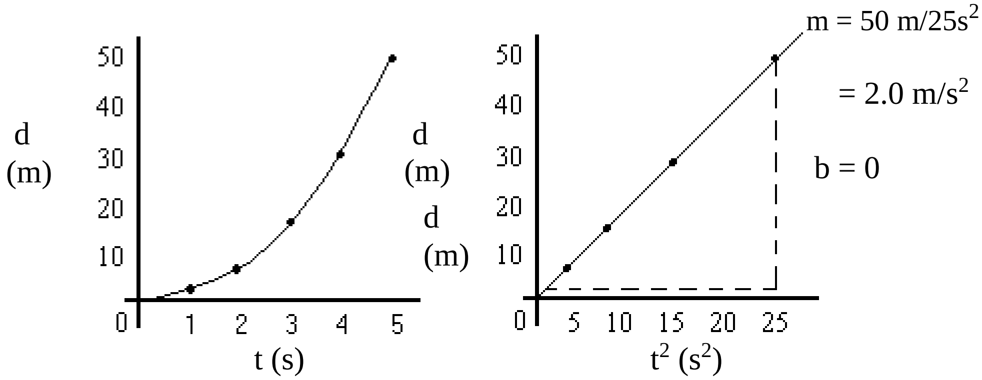
b)A car accelerated from 0 to 34 m/s in 7 seconds. Plot a graph of the trip and find the relationship between velocity and time.

Velocity (m/s)	0	5	11	14	22	26	30	34
Time (s)	0	1	2	3	4	5	6	7

II Exponential Relationships ($y \propto x^a$)

One method we can use to determine the equation of a curve is to recognize the relationship and then "straighten the line" by calculating the exponential value of one of the quantities. For example the displacement and time data below represents the motion of an object. The graph appears to be a squared relationship. By calculating the square of the time and re-plotting the data as d vs. t^2 we can find the equation of the curve.

displacement, d (m)	0	2	8	18	32	50
time, t (s)	0	1	2	3	4	5
$(\text{time})^2$,t^2 (s^2)	0	1	4	9	16	25



Once the graph has been straightened, you can state the equation for the line using the y = mx + b format given in part 1.

$$d = 2.0\ m/s^2\ t^2$$

*Note: this is the equation for both the curve and the straight line.

Practice Problems

1.The areas and diameters of various circles were recorded. Plot a graph of area vs. diameter and find the relationship between area and diameter.

Area, A (cm^2)	0.8	3.1	7.1	12.6	19.6
Diameter, D (cm)	1.0	2.0	3.0	4.0	5.0

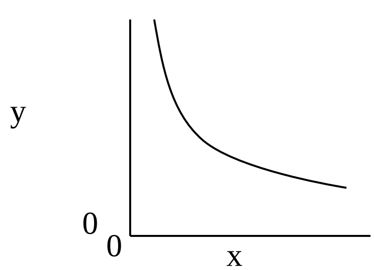
2.Forces were applied to threads of various diameters until each thread broke. Determine the relationship between breaking force and diameter for this material.

Breaking force, F (N)	7.8	29.4	69.6	124.5	198	282
Diameter, D (mm)	1.0	2.0	3.0	4.0	5.0	6.0

III Inverse Relationships ($y \propto 1/x$)

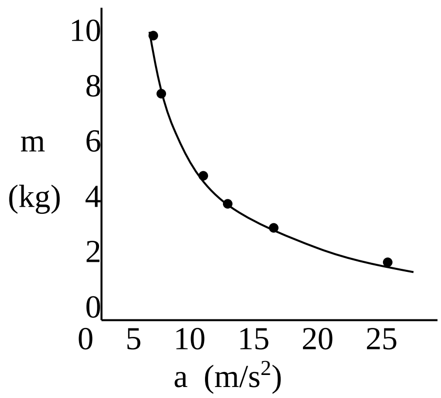
The third type of relationship is called an inverse relationship. When one quantity increases the other quantity decreases proportionally. Another way of saying the same thing is that the product of the two variables is a constant: yx = k. You can straighten the graph by calculating the inverse of one of the quantities and then plotting another graph.

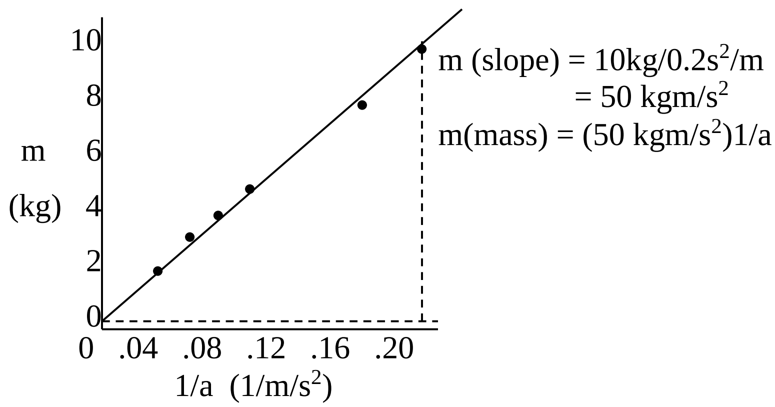
A graph of an inverse relationship will originally look like the following:



You must straighten this graph in order to write an equation for it. To do this, plot y vs. 1/x. It is usually more convenient to invert the values on the horizontal axis although mathematically you could invert either variable. Again note that when you do this that you have inverted the label, the symbol, the units as well as the numbers, which are now expressed as decimals. An example of an inverse relationship is shown below.

Mass (kg)	2	3	4	5	8	10
Acceleration(m/s^2)	24	16	12.5	10	6	5
1/a ($1/m/s^2$)	0.04	0.06	0.08	0.10	0.17	0.20





<u>Practice Problems</u>

1.A device is set up to measure the frequency and wavelengths produced by a piano. Plot a graph to show the relationship between frequency and wavelength. Assume frequency is the independent quantity.

Wavelength, λ	(m)	1.5	1	0.6	0.38	0.3	0.25
Frequency, f	(cycles/s)	200	300	500	800	1000	1200

SAFETY INSTRUCTIONS FOR PHYSICS STUDENTS

GENERAL

1.Maintain quiet behaviour during laboratory periods, so you can hear the teacher. Never rush. Always be prepared to stop quickly.

2.Study the purpose of an experiment before performing it. Ask questions about anything that is not clear to you.

3.NEVER ATTEMPT UNAUTHORIZED EXPERIMENTS. NO LABORATORY WORK MAY BE CARRIED ON WITHOUT THE TEACHER'S PERMISSION.

4.Keep the work area free of any books and materials that are not required for the experiment.

5.When you are finished the experiment, clean up and return all materials to their proper places. Turn the gas off under the bench as well as on top of the bench.

FIRE

1.Know the position of the nearest fire alarm and do not hesitate to use it if you see a fire or smell poisonous vapour.

2.When the fire alarm rings, shut off all burners, unplug all electrical devices and leave the room. The last one out of the room should close the door and report to the teacher that he/she was the last out.

3.Know the location of the fire blanket and fire extinguisher. If someone’s clothing or hair should catch fire, smoother the fire with your body until the fire blanket can be used.

BUNSEN BURNER AND HEATING

1.Learn to light a Bunsen burner correctly. Keep your head back from the burner during the lighting process especially if your hair is long. Also be especially careful with long clothing, beaded necklaces and similar jewelry.

2.Never leave an almost colourless Bunsen flame unattended. If the burner is to be kept lighted, shut off the air vent and decrease the gas supply to produce a flame resembling a candle.

3.Wear safety goggles when working with flames, heated liquids, acids or glassware.

4.The most common type of injury is a burn caused by touching objects which have just been heated. Determine whether an object is hot by bringing the back of your hand up close to it. Use cold water to alleviate pain and swelling.

5.Never carry hot equipment through a congestion of students.
6.Burns to your hands and skin should be treated immediately with cold water.

ELECTRICAL

1.When removing an electric plug from its socket, pull the plug and not the cord. Report frayed cords to the teacher. Bare electrical wires are extremely dangerous.

2.When you are working with electrical circuits, be sure that the current is turned off before you make any changes to the circuit.

3.Do not short out a dry cell. The wire used to do this can become dangerously hot.

4.If you are not certain about a circuit, have the teacher check it before turning the current on.

HAZARDOUS MATERIALS

1.Report any sharp edges on mirrors, prisms, glass plates, metal plates, etc., to the teacher so that these can be removed. Do not work with glass tubing that has jagged edges or edges which have not been fire polished.

2.Do not work with cracked beakers. Report them to your teacher.

3.Report all injuries to the teacher immediately regardless of how minor. Report even a minor nick!

4.If a thermometer breaks, inform your teacher immediately. Do not attempt to clean up the glass or mercury with your bare hands.

5.Mercury vapour is highly toxic. Never handle mercury with your hands. It will ruin gold or silver jewelry on contact.

6.Beware of what may appear to be drops of water on laboratory benches. They may be corrosive liquids.

<u>FORMAL LAB REPORTS</u>

1.All lab reports should be written in ink or typed and all graphs ***must*** be done on graph paper. Computer generated lab reports and graphs may be used (consult with your teacher) but make sure they represent ***your own work***. Your name, your partner's name, the block, date and course should be clearly printed at the top of your lab report.

2.**TITLE -**Each lab has a title that should be at the top of your lab write up. Start a new page for each lab.

3.**PURPOSE -**Describe in your own words what you are investigating, measuring or trying to discover in this experiment.

4.**MATERIALS** – A list of equipment and materials needed for the experiment. If they are already listed for you in the lab manual, simply write: see page ___ in the Physics 11 Lab Manual. Make sure you refer to the correct page number and the title of the book if the lab is not from the manual.

5.**THEORY and HYPOTHESIS** – Briefly describe the theory behind the experiment. Define any new terms. Make a prediction about the outcome of the experiment. Predict the shapes of any graphs you will have to draw and what type of relationship this will suggest between variables.

6.**PROCEDURE** – A list of the steps you will perform when doing the experiment. If you are following steps already listed for you, ***DO NOT WRITE THEM OUT AGAIN***, simply refer to the page number and title of the book the experiment is from. Changes made to a given experiment must also be stated. If the experiment is one you have developed yourself or has been suggested by your teacher, then you must write a detailed description of how to do the experiment. Use numbered steps to describe the process. The idea is that another Physics student anywhere else in the world should be able to duplicate your results.

7.**OBSERVATIONS -**Prepare data tables to record data. Where appropriate draw graphs and determine the slopes and equations required. Show sample calculations for each different calculation in the experiment.

8.**CONCLUSIONS -** Answer the problem stated in the purpose. Usually, this means answering the questions given at the end of the lab write up in the lab manual. If there are no questions provided, state your conclusions in sentence form. Separate each conclusion.

9.**SOURCES OF UNCERTAINTY** – List, in sentence form, those factors that have affected the results of your experiment. Calculate percentage error or difference as appropriate. Try to estimate approximate sizes of these uncertainties giving a justification for each.

Lab work is supposed to be fun, challenging and educational. Each lab you do has a specific purpose. Make sure that you are aware of what that purpose is!

If you have a good idea that you would like to try in place of a suggested lab, please see me first to iron out any potential problems.

NOTE:** MAKE SURE YOU COMPLETE STEPS 1 TO 5 ***AND PREPARE YOUR DATA TABLES ***BEFORE*** YOU COME TO DO THE LAB!!! (It's a time/safety thing!).

Data and Equations

Constants

$e = 1.60 \times 10^{-19}$ C

$m_e = 9.11 \times 10^{-31}$ kg

$n_{water} = 1.33$

$c = 3.00 \times 10^{8}$ m/s

$g = 9.80$ m/s^2

$G = 6.67 \times 10^{-11}$ Nm^2/kg^2

specific heat of water = 4200 J/kg^{o}C = 1.0 cal/g^{o}C

Equations

$d = \frac{(v_i + v_f)}{2} t$ $\quad d = v_i t + \frac{1}{2} at^2$ $\quad d = v_f t - \frac{1}{2} at^2$ $\quad v_f = v_i + at$ $\quad v_f^2 = v_i^2 + 2ad$

$W = Fd$ $\quad E_p = mgh$ $\quad E_k = 1/2mv^2$ $\quad E_h = mc\Delta T$ $\quad p = mv$

Power = W/t $\quad$ Impulse = $F\Delta t = \Delta p$ $\quad F = ma$ $\quad F = kx$ $\quad \mu = F_f/F_N$

$E = Pt$ $\quad n_1 \sin\theta_1 = n_2 \sin\theta_2$ $\quad n\lambda = d\sin\theta$ $\quad v = f\lambda$ $\quad 1/f = 1/d_o + 1/d_i$

$E = mc^2$ $\quad F = GMm/r^2$

$$t = \frac{t_0}{\sqrt{1 - v^2/c^2}} \qquad L = L_0\sqrt{1 - v^2/c^2} \qquad m = \frac{m_0}{\sqrt{1 - v^2/c^2}}$$

Greek Alphabet

Greek letter		Greek name	English equivalent	Greek letter		Greek name	English equivalent
Α	α	alpha	ä	Ν	ν	nu	n
Β	β	beta	b	Ξ	ξ	xi	ks
Γ	γ	gamma	g	Ο	ο	omicron	o
Δ	δ	delta	d	Π	π	pi	p
Ε	ϵ	epsilon	e	Ρ	ρ	rho	r
Ζ	ζ	zeta	z	Σ	σ	sigma	s
Η	η	eta	ā	Τ	τ	tau	t
Θ	θ	theta	th	Υ	υ	upsilon	ü,ōō
Ι	ι	iota	ē	Φ	ϕ	phi	f
Κ	κ	kappa	k	Χ	χ	chi	h
Λ	λ	lambda	l	Ψ	ψ	psi	ps
Μ	μ	mu	m	Ω	ω	omega	ō

Traffic Lab

Procedure/Observations

1.Pace out 10 comfortable steps in the classroom over the measuring tape.

2.Measure the distance to the best precision possible. ____________________

3. Calculate the distance of one pace. Use the same number of digits, as it is exactly 10 paces.

E.g. 7.21m / 10 = 0.721 m/ pace. Your value: _______ / 10 =____

3.Take a stopwatch and, once everyone is ready, walk down to the street with paper and pen/pencil.

4.Determine the speed of the objects listed in the table using a known distance and measuring the time. You will need to pace out the distance and sort out a signalling system with your partner.

5. Back in the classroom, convert speeds from m/s to km/hr, light year/s and nm/s. (light, and all electromagnetic radiation, moves at 3.0×10^8 m/s. There are 10^9 nm in a m.)

Observations/Analysis:

Object	Distance (m)	Time (s)	Calculated Speed			
			m/s	km/hr	Light year/s	nm/s
Car Heather						
Car 57th						
Student Walking						
Student Running						
Ant						

The Density of a Solid Object

Purpose: To determine how the density of a solid object can be calculated and to look at the uncertainties involved.

Materials: Solid block of aluminum or other solid element, triple beam balance, ruler, metre stick, 15 cm or 30 cm ruler, vernier caliper, micrometer calliper.

Introduction:

1. *Metre stick*

In making measurements with a metre stick, keep the following suggestions in mind: Since the end of the metre stick may be worn, start the measurement at some intermediate mark. (See Fig. 1-1.) Of course, the reading at the mark with which you start the measurement must be subtracted from the final reading.

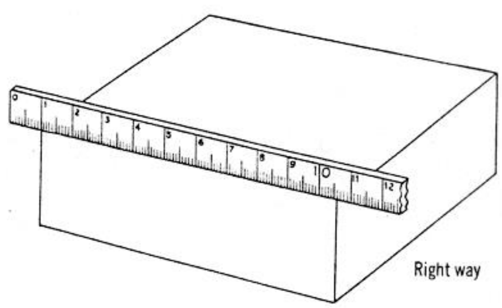


Figure 1-1

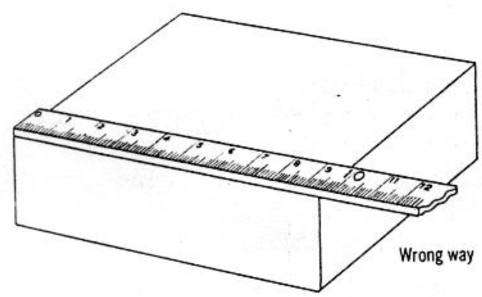


Figure 1-2

Place the metre stick on edge, as in Fig. 1-1. This will avoid errors that are easily made when viewing the stick in the flat position shown in Fig. 1-2.
Estimate the reading to the nearest 0.5 mm. In other words, the last digit of your measurement, which is an estimate, should be 0 or 5.

2. *Vernier caliper*

A vernier caliper consists of two metric and two English scales, as shown in Fig. 1-3. The fixed scales have a jaw at one end, the metric fixed scale being subdivided into centimetres and millimetres. The other jaw is attached to the sliding or vernier scales. The metric vernier scale is ruled so that *nine* millimetres is divided into *tenths.* From the enlarged scale of Fig. 1-4, it is evident that one division of the metric vernier scale equals 0.9 mm. When the jaws of the caliper are closed, the zero of the fixed scale exactly coincides with the zero of the vernier scale.

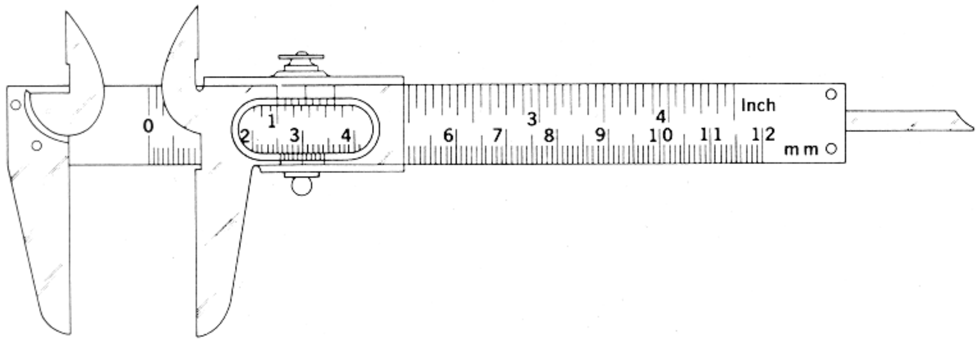


Figure 1-3

Moving the scale to the right 0.03 cm brings its third division opposite the three millimetre mark on *A*, and so on. That particular division on the vernier scale which coincides with a line or division on the fixed scale reads *hundredths of a centimetre.* When the vernier scale *B* is moved to the right until its *first* division coincides with the one-millimetre mark on the fixed scale *A*, it has been moved exactly 0.1 mm, or 0.01 cm, and the jaws are separated by that amount. When the vernier scale is moved to the right until its second division coincides with the two-millimetre mark on the fixed scale *A*, it has been moved a total distance of 0.2 mm, or 0.02 cm.

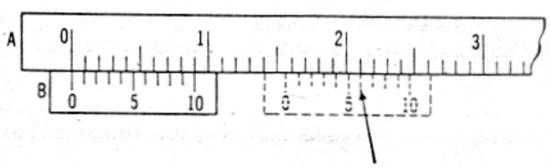


Figure 1-4

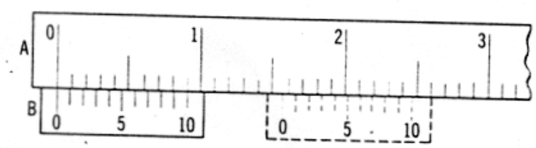


Figure 1-5

To use the caliper, separate the jaws, place the object to be measured between them, and close the jaws firmly on the object. Then tighten the set screw, if there is one, enough to keep the vernier scale from moving while it is being read. Suppose the vernier scale now occupies the position shown by the dotted fines of Fig. 1-4. The zero of the vernier scale shows that the jaws are separated by more than 1.5 cm and less than 1.6 cm. *Centimetres and tenths of centimetres are read on the fixed scale. Hundredths of centimetres are read from the vernier scale by locating that particular division on the vernier scale which coincides with a division on the fixed scale.* As indicated by the arrow, it is No.6. Therefore, the correct reading is 1.560 cm. If no division on the vernier scale coincides exactly with a division on the fixed scale, then the last digit of the measurement should be a 5. Thus, the correct reading for Fig. 1-5 is 1.565 cm. To measure the inside diameter of a tube or hollow cylinder, the upper parts of the jaws are used. Keep in mind the fact that centimetres and tenths of centimetres are read from the fixed scale, while hundredths of a centimetre are read from the vernier scale.

3. *Micrometer caliper*

A micrometer, Fig. 1-6, consists of several parts. The flat end of a set screw forms one surface against which the object to be measured rests. It is called the anvil. The end of the spindle forms the other surface. Within the caliper, the spindle is an accurately threaded screw

which can be moved back and forth through the frame of the caliper as the thimble is turned. If the micrometer is graduated in metric units, the threads on the spindle may have a pitch of exactly one millimetre, provided the edge of the thimble is divided into 100 equally-spaced divisions. This means that the opening at C is opened or closed *exactly one millimetre* when the thimble is given one complete turn in a clockwise or counter-clockwise direction. When the spindle rests firmly, but not too tightly against the anvil, the zero on the thimble should exactly coincide with the zero mark on the barrel of the frame. Turning the thimble through one-hundredth of a complete revolution changes the opening *one- hundredth of a millimetre.*

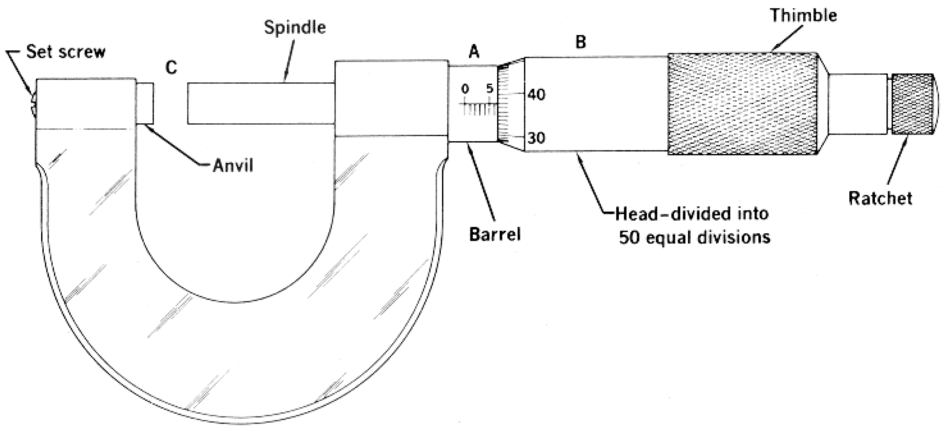


Figure 1-6

If the threads on the spindle have a pitch or interval of half a millimetre, then the thimble must be given two complete turns to open or close the opening at C by one millimetre. In such a case the thimble is divided into 50 equal divisions. Hence, twisting the thimble through one division opens or closes the space at C by one-hundredth of a millimetre. Millimetres are read from the scale on the barrel; hundredths of a millimetre are read from the scale on the thimble. For example, the caliper of Fig. 1-6 shows by the scale on the barrel that the opening at C is more than 6 mm and less than 7 mm. Furthermore, the thimble scale is closer to 6 mm than it is to 7 mm. Division number 38 on the thimble coincides with the horizontal line on the barrel. Therefore, the reading of the caliper is 6.380 mm. If the thimble scale had been closer to 7 mm than to 6 mm, the thimble must have been turned 50 scale divisions past 6 mm and then an additional 38 scale divisions. The reading would then be 6.880 mm. If the horizontal line on the barrel does not coincide with a division number on the thimble, then the measurement should be estimated to the nearest 0.001 mm.

As the caliper is closed, it takes only a slight amount of force to make the zero line of the thimble coincide with the horizontal line of the scale on the barrel. In making any measurement, this same force must be used in closing the caliper on the object being measured. It is easy to injure so delicate and sensitive an instrument. A mechanic tightens his micrometer so the object will slip "stickily," as a nail pulled along a magnet. Some calipers have a ratchet thimble which has enough friction to close the caliper, but turns when the caliper is closed. This protects the instrument.

Procedure:

1.Measure the mass of the object using the balance.
2.Measure the appropriate dimensions of the object using the ruler.
3.Repeat your measurements using a vernier calliper and micrometer calliper.

Observations:

1.Record the mass and dimensions of the object. Be sure to identify the possible uncertainty in each measurement.
2.Calculate the minimum volume of the solid object by using the smallest possible value for each dimension.
3.Calculate the maximum volume of the object by using the largest possible value of each dimension.
4.Calculate the minimum density of the object
5.Calculate the maximum density of the object

Questions:

1.How many significant figures are there in each of your measurements?
2.When calculating the minimum density, which two of the following four quantities do you use: minimum mass, maximum mass, minimum volume, maximum volume?
3.Which of the four above mentioned quantities do you use to find the maximum density?
4.What is the percentage difference between the maximum density and the minimum density?
5.How would you obtain the average density of the object?
6.How many significant figures are there in your calculated average density?
7.Compare your average density with the known density of aluminum (or the element you used). What is your percentage error? Give as many reasons as you can to explain this error. Do this for each measuring instrument.

Pendulum Lab

Name____________________Block_____

Partners Name____________________Mark___/10

Aims: Find the relationship between the period of a pendulum, T, and 1. the length of a string, L, 2. the angle between the string at the initial drop position of the bob and vertical, A. Use your graphing skills to determine the equation for each relationship. Fill in the blanks on this sheet and staple your graphs when submitting.

Hypothesis and Background Theory:

Period, T, is the time for a repeating event. For a pendulum it is the time for the bob to swing and come back. The length, L, is the distance from the securing point to the centre of mass.

The relationship between period and length is $T = 2\pi\sqrt{L} / \sqrt{g}$ where g is the gravitational field strength, 9.8 N/kg. This is assuming negligible resistive forces. When you graph T verses length it will be a curve, you can straightened by graphing T vs the square root of the length. The slope of that graph is $2\pi/\sqrt{g}$ or 2.0 s/$\sqrt{m}$ (note the units are seconds and root of metres – be sure to convert lengths into metres).

What do you think is the relationship between period and the initial drop angle (A)?
Answer in this space provided: (1 mark)

Give reasons for your hypothesis(1 mark)

Materials and Procedure: Get a 1m+ length of string, a stand with a clamp, a small (100 or 200g) weight, a stopwatch and a metrestick for your group of 2. You need permission for any groups larger than 2. Each individual completes their own report every lab.

Add any details of your procedure in the space provided.

Part 1. Vary the length of the string (wrap it around the clamp, for example) for 10 points of data. Take the average of 3 swings. – keep all other variables constant if possible.

Part 2. Vary the drop angle for 5 points of data – keep length constant. Take the average of 3 swings.

Observations: (1 mark)

Part 1 Length of a Pendulum

Length, L (m)										
Square root of the Length (√m)										
Time for 3 swings (s)										
Period, T (time for one swing) (s)										

Part 2 Initial Drop Angle of Pendulum

Initial Angle, A (degrees)					
Time for 3 swings (s)					
Period, T (time for one swing) (s)					

Analysis: Graph T vs root L and T vs A each on a separate page and find the equation relating the variables, include units and reasonable decimal place(estimate of precision). (3 marks)
Calculations for the graph should be completed directly on the graph. (1 mark)
Calculate the percentage error using the following equation(1 mark)
percentage error = |experimental value-theoretical value|/theoretical value x 100%
The experimental value is the slope of your T vs √L graph and the theoretical value is the value predicted in the theory (2.0 s/√m)

Results and Conclusion: (1 mark)

Sources of Uncertainty: (1 mark)

Uniform Motion

Purpose: To analyze the motion of an object travelling at a constant velocity.

Theory :

There is a direct relationship between displacement and time for an object moving at a constant velocity. A graph of displacement, **d**, versus time, **t**, will have a linear relationship with the value of the slope representing velocity, **v**.

$$d = vt$$

Procedure:

Part 1:

1.Use the ticker tape from the first investigation or pull a short strip of ticker tape through the timer at a constant speed as smoothly as possible.
2.Choose about 11 points that are reasonably evenly spaced for analysis by the group. Label the first point as the reference point (time 0.00 s) and measure the displacement of each of the other points from this reference point.
3.Prepare a data table (as shown below) under the **Observations** heading in your lab report. Calculate the time interval between each dot. Use this information to complete the time column in your data table. Include a copy of the ticker tape in your report.

Motion of Tape Pulled Smoothly

Displacement from start (cm)	Dot (number)	Time (s)
	1	0.00
	2	
	3	
	4	
	5	
	6	
	7	
	8	
	9	
	10	

4.Plot a position vs. time graph and draw a best-fit line through the points. Find the equation of the line.

Questions:

1.Look at your ticker tape. Are there any points that do not seem evenly spaced? What do you notice about their position on the graph?
2.Use your final value for displacement and the total time to calculate the average speed of your ticker tape. How does this compare to the slope of your graph? What does the slope represent?
3.Will every group have the same value for the slope? Why or why not?
4.What shape would the graph have if the motion was still uniform but slower? Faster?

Part 2:

1.Using a new piece of ticker tape, pull the tape slowly at a constant speed first and then suddenly increase the speed of the tape through the timer. Try to keep the faster speed constant as well.
2.Choose at least 11 points around the area of the tape where the dots start to become spread out (make sure you have points on both sides of this area). Measure the displacement as before and record this information, along with the time in another data table. Include the tape in your lab report.
3.Make a position vs. time graph for your data. You should have two connected lines on the graph (each with a different slope), one for the slow motion and one for the fast motion. Find the slope of each straight portion.

Questions:

1.Use your final value for displacement and the total time to calculate the average speed of your ticker tape. Calculate the average velocity by finding the slope of the line connecting the first and last points on your graph. Compare these two results.

Conclusions:

1.Write a conclusion. It should include any equations you calculated and your assessment of how closely your data fits your hypothesis.
2.Estimate the uncertainty of your measuring devices. (i.e. ruler and recording timer) Analyze and list your sources of uncertainty. What factors may have made the motion not perfectly smooth?

Uniform Acceleration

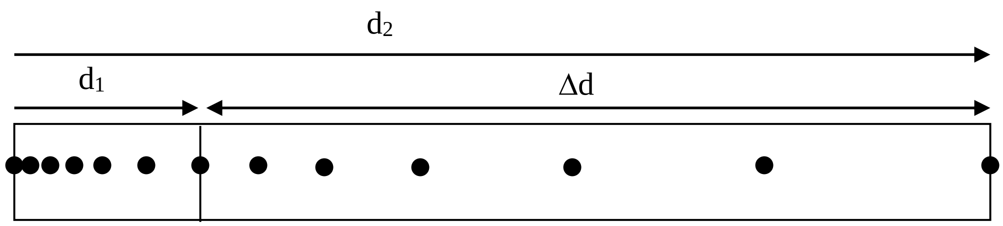
Purpose:

1.To determine the rate of acceleration of a cart traveling down a ramp.
2.To measure the distance the cart traveled by means of a v - t graph.
3.To measure V_{avg} from a d-t graph.
4.To compare the acceleration with the slope of a d-t^2 graph.

(**Reminder:** Your conclusion should include a discussion of each of the above items)

Procedure:

1.Attach a piece of ticker tape to the back of a cart using masking tape.
2.Run the cart down a ramp while the timer strikes the tape. Get 1 tape per group member.
3.Every 6 dots is a 0.10s time interval. Measure d_1, d_2, and calculate $\Delta d = d_2 - d_1$ as shown below:



4.Record your measurements in data tables as shown:

Observations

Time (s)	d from start
0	
0.1	
0.2	
0.3	
0.4	
0.5	
0.6	
0.7	
0.8	
0.9	
1	

time (s)	Δd	V average
0.05		
0.15		
0.25		
0.35		
0.45		
0.55		
0.65		
0.75		
0.85		
0.95		

5.The distance traveled per interval divided by the time per interval (0.10s), represents V_{avg} for that time interval. Calculate V_{avg} for each interval and record the values in the second data table shown above.

6.Plot a graph of V_{avg} vs. time. Note that V_{avg} is best represented as occurring in the middle of each time interval and not at the end or beginning of an interval.
7.Determine the slope of your V_{avg} vs time graph and write an equation for your line.
8.Cut your tape into 0.10s interval segments (be sure to have finished measurements first!) and paste this tape onto a graph grid which is labeled V_{avg} vs time.
9.Calculate the area under the line on your V_{avg} - t graph. Make sure you pay attention to the units involved.
10.Plot a d - t graph. Draw a tangent to the slope of the d-t curve at a point halfway down the incline and at the end of the incline calculate the slope of the tangents.
11.Use your graphing skills to straighten the d-t line and find an equation for the line.

Questions:

1.What does the slope of the V_{avg} vs. t graph represent?
2.Calculate the area underneath your V_{avg} vs. t graph. Pay attention to the units you are using. What does this area represent?
3.Compare your V_{avg} vs. t graph to the graph you made from the segments of ticker tape in step 6.
4.Describe how the motion of the cart down the ramp relates to the shape of your d – t graph. What type of relationship exists between d and t?
5.What is the equation of the line for your straightened displacement-time graph? Compare the slope of this graph to the slope of your V_{avg} vs. t graph. How are they related?
6.Describe what an a-t graph should look like for an object undergoing uniform acceleration.

<u>Acceleration Due to Gravity</u>

Purpose: To measure the acceleration of an object as it falls towards the surface of the Earth.

Materials: recording timer, ticker tape, 50g and 100g mass, tape

Procedure:

1.Attach the ticker tape to the 50 g mass and thread it through the recording timer.
2.Holding the recording timer horizontally, drop the mass so that it pulls the tape through the recording timer.
3.Select an appropriate time interval (e.g. every 3 dots is 0.05 s) and collect displacement and time date from your ticker tape.
4.Plot a graph of displacement vs. time and straighten if necessary to get an equation for your line.
5.Calculate the Δd between each interval.
6.The distance traveled per 0.05s, (Δd/0.05s) represents V_{avg} for that interval. Calculate and record the V_{avg} for each segment.
7.Plot a graph of V_{avg} vs time. Note that the V_{avg} occurs half way through each time interval and not at the end of the interval. V_{avg1} occurs at 0.025s, V_{avg2} occurs at 0.075s and so on.
8.Determine the slope of your V_{avg} vs time graph and state the acceleration of the falling mass. How close is it to g?
9.Repeat the above for to 100g mass.

Observations:

Time (s)	Time squared (s^2)	d from start	
0.00	0.00		
0.050	0.0025		
0.100	0.0100		
0.150	0.0225		
0.200	0.0400		
0.250	0.0625		
0.300	0.0900		
0.350	0.122		
0.400	0.160		
0.450	0.202		
0.500	0.250		

Time (s)	Δd	$V_{Average}$
0.025		
0.075		
0.125		
0.175		
0.225		
0.275		
0.325		
0.375		
0.425		
0.475		

Questions:
1.Once you have the equation for each graph, what does the slope represent?
2.The accepted value for acceleration due to gravity is: $g = 9.80 m/s^2$. Calculate the percentage error in your results.
3.Remember to list sources of uncertainty for your experiment.
4.Comment on the shapes and slopes of the graphs for the two different masses.

Using a Webcam to Study Motion.

1. Open the **Capture** program on the desktop.
2. Leave the capture options as **use VFW.**
3. You should see the image on the screen. If it is not moving, under **options** set **preview.**
4. Set up your apparatus and move the webcam until the range of motion of the object uses the whole screen. Include a known length (metre stick) in the setup.
5. Click on **Start Capture**.
6. Set the frame rate to an appropriate value, 15 frames per second is usually adequate. Leave capture method as directly to disk.
7. When everything is ready, click **OK** to start recording then start the motion of the object.
8. Click on **Stop Capture** when you are done.
9. Save the file to the folder "studentvideos" using a name you will remember <u>**with no spaces**</u> and <u>**add the extension .avi or it will not be read**</u>. **(old program)**
10. Minimize the capture window. On the desktop, click on **Video Analysis** and open your video.
11. Play your video. Use **Pause** and **step** to find the location where you want to start measuring data. Click on **Mark Min Frame.** Do the same for the end of your data with **Mark Max Fame.**
12. Click on **Stop** and choose to set the frame rate and scale.
13. Set the frame rate to 15.
14. To set the scale, when indicated, click with the left mouse button on one end of the metre stick and then click with the right mouse button on the other end. Indicate that this distance is one metre.
15. Use the left mouse button to click on a point of the object. Use the right button to step to the next frame. Determine the uncertainty in your measurement of position. If you move the mouse slightly, how much does the position change?
16. If you have 2 objects, click on **data set 2** and set the data.
17. Click on **graphs** and check that your data looks reasonable. Keep clicking until you see data tables.

If you just want the graphs from the program, you can find the slope of linear graphs(click on **slope**) and print the graphs and data table off the World in Motion program. Print one copy per group member. If you need to analyze the data you should:

18. Click on **Click Here to Copy all Data to Clipboard.**
19. Open a spreadsheet program (like Excel) and paste in the data.
20. Go back to your video. When you like how you look, press ALT/Print Screen. Paste the image into your spreadsheet program.
21. Save the spreadsheet in studentvideos folder.
22. Save to your usb drive or e-mail the data to yourself and your group mates.
23. At home, use a spreadsheet program to graph the data and analyze it. (instructions next page)

<u>Graphing Using a Spreadsheet</u>

<u>Do it right or do it by hand!</u>

<u>Notation: OO – open office Ex for Excel</u>

To open an open office spreadsheet using Excel, you may have to install open office on your home computer.

1. Put your data in columns. If needed, modify the data using a predicted equation. For example, if the A and B data are parabolic you can square one data set using the equation =B2^2 in the C column and fill down(click on the corner and drag down). Always start with = and use capital letters for the cell column.
2. To select the data to be graphed, left click on the first data point of the independent variable and hold down the button while you move down over the data. To select the second data set, hold down the ctrl button then left click and drag down. Only click once per set as multiple clicks will result in extra sets.
3. Click on Insert then Chart once the data has been selected.
4. Select x-y scatter plot with no lines.
5. Include a title and label each axis(under Chart Elements in OO). Be sure to include units.
6. Click on legend and hide the legend or unclick show legend.
7. Ex - Double click on a data point. OO – right click selec insert y uncertainty bars
8. Give a value for the x and y error bars(uncertainty bars). Generally the uncertainty should be half the smallest unit measurable by your measuring device. OO doesn't have x bars, so translate all uncertainty to y – describe in the analysis of your lab.
9. Ex - click on Chart and add trendline OO- right click on a data point and add trendline
10. If you straightened your data properly, choose linear. If you were unable to straighten the data you can try polynomial.
11. Under options select that the equation be shown on the graph.
12. Once you have an equation, click on it. Change the variables from x and y to the quantities you are graphing, like force, F, or mass, M. (open office doesn't have this function, just change it in the body of your lab report)
13. Change the significant figures to a reasonable number. If the curve is very close to all the data points you would use more significant figures than if it is far. IBers should use the uncertainty to determine the sig figs.
14. IBers - The uncertainty in slope should be determined using the max/min lines. From the bottom of the uncertainty bar of the first data point draw a line to the top of the uncertainty of the last point is roughly how it should be done. Then one from top to bottom. If you have points that are way out, you may want larger range for max/min. Find the slope of the max/min lines, take the difference and divide by 2. This is the uncertainty of the slope- keep it to one digit and round the slope to the precision of the uncertainty. e.g. max slope 3.82m/s, min slope 3.40m/s, uncertainty would be 0.2 m/s, or the slope would be 3.6 +/- 0.2 m/s. NOT 3.61 +/- 0.21 BAD.

15. Keeners, go back to the spreadsheet. Select 4 empty cells in a square. Type =LINEST(y values, x values, TRUE, TRUE) for example =LINEST(B3:B9, A3:A9, TRUE, TRUE) Press Ctrl/Shift/Enter at the same time for PC or the command key for Macs. For Open Office, use semicolons instead of commas:

=LINEST(B3:B9;A3:A9;TRUE;TRUE) don't forget the Ctrl/Shift/Enter. (note: was giving me problems on Office 2010 – if it doesn’t work for you, just skip it)
IBers, though this is a better method for determining uncertainty, you shouldn't use this unless you demonstrate your understanding of the underlying method.
The top left cell is the slope with its uncertainty underneath, the top right cell is the y-intercept with the uncertainty underneath. Include the uncertainty in the equation.

16. Include units in your equation. Think “what are the units of the rise and run? What are the units of the slope and intercept?” For example, your equation should look like: d = 2.55 +/- 0.07 m/s t - 0.03 +/- 0.02 m (linear) or
    a. d = 4.8 m/s^2 t^2 + 0.31 m/s t + 0.2 m (polynomial) it should **NOT** look like
    b. y = 0.508473 x + 0.049743 (very bad...grrr open office).
17. Check that the graph is clear with the equation easily read. If necessary, resize portions of the graph by right clicking then moving a corner or side.
18. Right click on the graph and click copy then paste in your lab report. Copy and paste your data into a table in your report. Include any equations you used. I've had problems copying graphs from open office, if it doesn't work just print them off the spreadsheet and give me a hard copy.

19. A power-point of the process can be found on the wiki:
20. http://physics-pages.wikispaces.com/Graphing+tips

“World-in-Motion” – Acceleration Due to Gravity

Purpose: To derive a value for the acceleration due to gravity by analyzing a video segment showing an object in free fall.

Procedure: Choose ***ONE*** of the following methods:

1.Computer
-load the “World-in-Motion” program
-open and load the video file from the D drive
-double click on “video”
-click on “freefall”
-choose a program to analyze a) a falling apple b) a shoe c) a big ball d) a small ball e) a beach ball f) a beach ball g) a small ball
-when you have finished marking the points go to “Graph”
-choose Y direction
-choose position vs. time
-print the graph and use it for your data

2.Video Disk
-Choose one of the following programs: A 42, A 43, A 46
-Load the segment by choosing “Chap/Frame”, key in the number you want (e.g. “4” “8”), hit “search”
-Play – shows the whole segment
-FWD – goes one frame at a time
-Disp – shows the frame count which you can convert to time
-Stop the motion every 0.1 s or so and record the displacement and time
-Sketch the pattern and use the data for analysis

Force, Mass and Acceleration

Purpose: Determine the relationship between the mass of a hanging weight, the mass of a cart and the acceleration of the mass and cart system.

Procedure:
1. Attach a pulley to the end of the table using a clamp, some string and a stand. Attach string to the cart and to a mass and hang over the pulley as shown. The weights on the cart should be around 10 times the falling weight to facilitate the time measurements. One student will need to hold the stand, another will hold and catch the cart while a third will time using a stopwatch. Students should change jobs between trials.

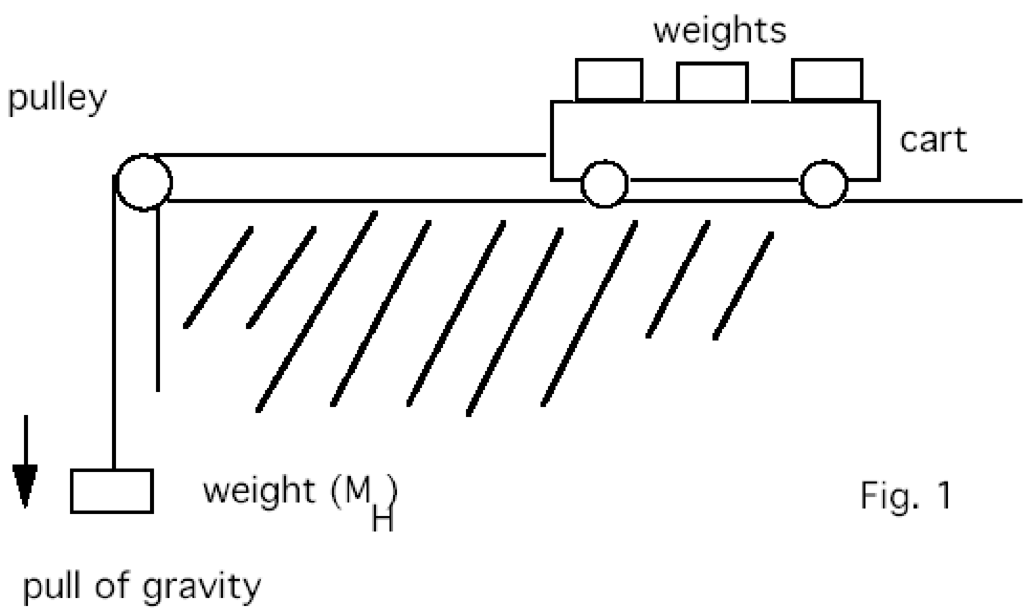


Fig. 1

Time the cart accelerating over a measured distance.
Repeat 3 trials and average the times.
Vary the weights on the cart and repeat the experiment. Measure the weight of the cart using a spring scale and calculate the mass using Weight = Mass x 9.8 N/kg.
In a separate data table, vary the hanging mass and observe the effect on the acceleration with a constant mass on the cart.
Now set the total mass constant and vary the distribution. For example, have 100g hanging and 2.7kg cart with 700 g on it, then have 200g hanging and the 2.7 kg cart with 600g on it.
if a is constant and $v_i = 0$, then $d=1/2\ at^2$ so $a = 2d/t^2$
Make three graphs: 1. acceleration versus total mass of the cart and hanging mass (hanging mass is constant) 2. acceleration versus the hanging mass (mass of the cart is constant) 3. acceleration verses hanging mass (total mass is constant)
Derive an equation from each graph.

Part 1:
Hanging Mass, M_H___________ (keep constant)

Mass of cart and weights on the cart. (kg)	Time (s) to move distance d_______________ Trial 1	2	3	avg	Acceleration m/s^2 $A=2d/t_{avg}^2$

Part 2:

Total mass of cart and weights on the cart_____________________(keep constant)

M_H Hanging Mass(kg)	Time (s) to move distance d_______________ Trial 1	2	3	avg	Acceleration m/s^2 $A=2d/t_{avg}^2$

Part 3:

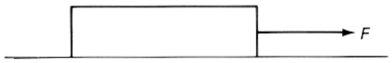
Total mass of carts, weights on cart and hanging mass M_H ___________________(keep constant)

M_H Hanging Mass(kg)	Time (s) to move distance d_______________ Trial 1	2	3	avg	Acceleration m/s^2 $A=2d/t_{avg}^2$

<u>**Sliding Friction**</u>

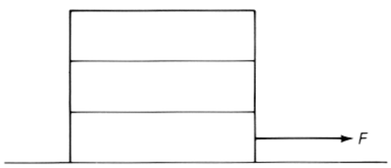
Purpose: To find out what factors determine the force of friction on a sliding wooden block.

Materials: 3 wooden blocks, spring balance, ruler.

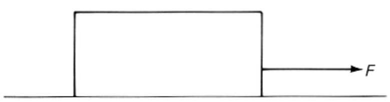


One block lying flat

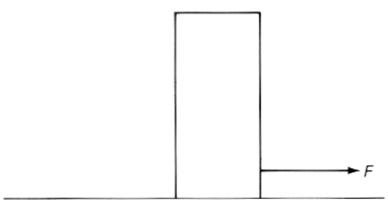
Two blocks lying flat



Three blocks lying flat



One block on its edge



One block on its end

Procedure:

1.Measure the length, width, and height of a block. Calculate the area of each face.
2.Use the spring balance to find the force of gravity on the block, in newtons.
3.Pull one block along the desk on its largest face at a steady speed, and record the force required.
4.Repeat, using piles of two and three blocks, at the same speed as in step 3.
5.Pull one block along, first on its edge and then on its end, again at the same speed. Record the force required each time.
6.Pull one block along, first at half the original speed and then at twice the original speed. Record the force required each time.

Questions:

1.Does the speed of the block have a significant effect on the force of friction? For example, to go twice as fast, do you have to apply twice the force?
2.Does the area in contact with the desk affect the force of friction significantly? When the area is twice as much, does the force double?
3.When you double of triple the number of blocks what happens to the force of friction.
4.The coefficient of friction, represented by the Greek letter mu (μ) is calculated by dividing the force of friction between the two surfaces by the force pushing the two surfaces together, both expressed in newtons. In this experiment, the force pushing the two surfaces together is the force of gravity. Calculate the coefficient of friction for each of the above cases. It will be roughly the same for each case, though it can vary considerably.
5.Find the average value of the coefficient of friction for the kind of wood you are using, sliding on the kind of desk you have. Each different combination of materials will have its own coefficient of friction.
6.If you were to make the desk or the block smoother, what effect would this have on the coefficient of friction?

Extension: Use blocks that have different materials attached to one side. Determine the coeffcient of friction for these different surfaces.

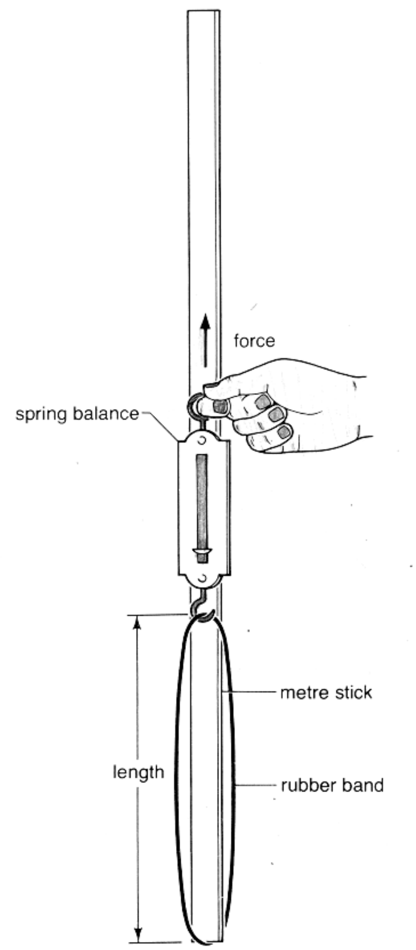
Elastic Forces

Purpose: To determine the relationship between the length of a rubber band and the force applied.

Materials: large rubber band, spring balance, metre stick.

Procedure:

1.Place the metre stick flat on the desk. Hook one end of the rubber band around the end of the meter stick and hook the other end onto the spring balance.
2.Stretch the rubber and by pulling on the spring balance until it is about twice its natural length. As you do this, stop every few centimetres and record the length of the rubber band, in metres, and the elastic force, in newtons. You will need at least 10 readings.
3.Plot a graph of the elastic force against the length. most of this graph will be a straight line. Draw this straight line back to the cross the horizontal length axis. The point where it crosses will tell you the length of the rubber band if no force is stretching it, that is, when it is natural length.
4.Calculate the slope of the straight-line part of the graph. This is called the spring constant of the rubber band, and it is measured in newtons per metre.



Measuring the length of a rubber band as the force acting on it increases

Questions:

1.What would the graph look like if a stronger, thicker rubber band were used? How does the spring constant change when a stronger rubber band is used?
2.What would the graph look like if the elastic force were plotted against the increase in length instead of against the total length, of the rubber band (increased in length = total length - natural length)?

Power

Purpose: What is the power generated by a physics student running up a flight of stairs?

Materials: physics student(s), kilogram bathroom scale, metre stick, stopwatch.

Procedure:

Measure your mass using the bathroom scale. Make sure you are using kilograms. Calculate the force of gravity on your body using $F_g = mg$. Use this value for force in your work calculation.
Measure the height of one step. Count the number of steps and multiply to find the vertical height you will rise, in metres.
Have another member of your group use the stopwatch, to measure the time it takes you to run up the stairs, from a standing start, in seconds.
Calculate the work done in lifting your body up the stairs.
Calculate your power using appropriate units.

Questions:

1.How does your power compare to the power of other students in your class?
2.What would your power be in horsepower? How does your power compare to that generated by a car engine?
3.Assuming you didn't get tired and slow down, use the power you calculated to determine how long it would take you to run to the top of Grouse mountain – a change in elevation of 854 metres?
4.Colin Dignum (68 kg) did the Grouse Grind in only 28 minutes and 27 seconds. What is his power? Compare it to yours.

Specific Heat Capacity

Purpose: To experimentally determine the specific heat capacity of various metals and heat of fusion of ice.

Materials: Styrofoam cup, beaker, hot plate, various metal samples, string, thermometer, balance and an ice cube.

Theory: Assuming the heat gained by the water is equal to the heat lost by the metal:

$$\Delta E_{hw} = m_w c_w \Delta T_w \quad = \quad \Delta E_{hm} = m_m c_m \Delta T_m$$

therefore: $c_m = -m_w c_w \Delta T_w / m_m \Delta T_m$

where: ΔE_{hw} = the heat energy gained by the water (J)
m_w = mass of water (kg)
c_w = specific heat capacity of water (J/kg ^oC)
ΔT_w = change in temperature of the water (^oC)
ΔE_{hm} = the heat energy lost by the metal (J)
m_m = mass of the metal (kg)
c_m = specific heat capacity of the metal (J/kg ^oC)
ΔT_m = change in temperature of the metal (^oC)

For ice, heat gained by ice = heat lost by water
$m_{ice}H_{ice} + m_{ice}c_w\Delta T_{ice} = - m_w c_w \Delta T_w$
solve for H_{ice}

Procedure:

1.Fill a beaker about half full of water and boil it.
2.Record the mass of 4 Styrofoam cups individually or zero the scale with one then fill it about quarter full with tap water, the fourth should be 3 quarters full. Record the mass of the water in each.
3.Weigh each metal. Using a string or tongs, carefully lower the metals into the boiling water(metals can break the beaker). Let them stay in the water for about 5 minutes.
4.Record the initial temperature of the cold water in each cup.
5.Put the hot metal into the cold water. Cover the cup and stir. Record the highest temperature reached after the metal has been placed inside the cup. Put the ice in the fourth cup and record the lowest temperature
6.Calculate the specific heat capacity of the metal and heat of fusion of the ice.

Questions:

1.Compare the specific heat capacities and heat of fusion that you found to the accepted values.
2.Make sure you list the sources of error in your experiment and <u>give evidence.</u>

The Efficiency of a Kettle

Purpose: To determine the efficiency of an electric kettle.

Materials: electric kettle, thermometer, stopwatch, beaker.

Procedure:

1.Prepare a data table like the one shown below:

Mass of water (kg)	Temperature of water (°C)		Temperature change (°C)	Time for heating (s)	Power of kettle (W)
	initial	final			

2.Look on the bottom to find out how much electric power the kettle uses. Note the power in watts.
3.Put a known mass of water in the kettle. (1000 mL of water will have a mass of 1 kg).
4.Measure the initial temperature of the water and then plug in the kettle and start the stopwatch. Keep track of the temperature and the time.
5.When the temperature is around 60 ^{o}C, start looking at the stopwatch, and, when it indicates the end of the next full minute, pull out the plug of the kettle. Record the time and then stir the water thoroughly. Record the highest temperature reached by the water.

Questions:

1.How much electrical energy was used by the kettle?
2.How much heat energy was absorbed by the water?
3.What is the efficiency of the kettle?
4.Where did the rest of the energy go?

"World-in-Motion" - Impulse

Introduction

This CD-ROM program allows one to look at the frame-by-frame scenes of the videotaped collision between a moving object and a barrier. The program also allows you to plot a variety of graphs that illustrate and measure various physical quantities as they vary with time. The construction of appropriate graphs will be used to investigate time intervals and force magnitudes in the following video clips.

Investigation

You will be looking specifically at two separate videos. These are labelled "Imp2d aa" and "Imp2d a". Load and analyze each separately. Complete each analysis before moving on to the next.

A. Imp2d aa

This focuses on a disc colliding with a vertical barrier. The centre of mass of the disc is clearly marked.

1.Determine using appropriate graphs, written explanations, and calculations
i.The time over which the collision occurred
ii.The magnitude and the direction of the average force that the barrier exerts on the disc (Hint: obtain both F_x and F_y values from "p vs. t" graphs and consider slope)
iii.The magnitude of the maximum force that the barrier exerts (Hint: consider "F vs. t" graphs and compare with ii)
iv.Whether momentum is conserved in this collision (Careful! Consider the barrier!)
v.Whether this collision is elastic (Hint: consider "v vs. t" graphs)
vi.What percentage of the initial kinetic energy is conserved

2.Are the results of this collision ones that you would expect? Explain.

B. Imp2d a

This focuses on a "ball" colliding with a horizontal barrier. This is a more realistic situation as the centre of mass is not marked. Do your best to determine its approximate position in each video frame.

1.Repeat instructions 1(i) to 1(vi) in the above analysis for "Imp2d aa".
2.Are there any inconsistencies (irregularities) in your graphical data? Explain.

"World-in-Motion" – Conservation of Momentum

Purpose: To investigate (i) the law of conservation of momentum in a collision between 2 gliders and (ii) whether the collision is elastic.

Procedure: * **Read all the instructions *before* you begin.**

1.View the video clip "col1d-l" in its entirety.
2.Advance the video frame by frame, labelling each object (using a different colour) at a fixed point for each frame.
3.Consider and estimate the likely amount of uncertainty for the points that you have labelled.
4.Plot graphs of "p" vs. "t" for each object and a graph of "P_{total}" vs "t" for the combined system.
5.Is the momentum conserved? Calculate the % difference of the total momentum before and after the collision.
6.Was the collision elastic? Calculate the ratio of E_k(after) / E_k(before) and express the answer as a percentage.

Note: Velocities will have to be calculated for each object both before and after the collision interval.

Explosion Lab

Objective:
To explore the conservation of momentum in an explosion.

Hypothesis/Background Theory:
Momentum is conserved in a closed, isolated system. Is the system likely to be isolated?
$p=mv$ $P_{ti} = P_{tf}$

Procedure:
Cart "explosion"
5.Create a table with M1, M2, D1 and D2 and 3 trials and average of T1 and T2
6.Take out two wooden carts, a force scale, 2 wooden rulers, 2 stopwatches and a 1kg mass. Place textbooks to stop the carts from rolling off the table but allow them to roll a full metre.
7.Weigh one cart using the force scale DO NOT PUT ON ELECTRONIC BALANCE, calculate and record M1. Then do the same with the second cart but add one kg then record as M2.
8.Set the two carts with the spring side facing each other, beside the two rulers
9.Prepare 2 stopwatches for the 2 carts
10.Push the carts together so that the springs are compressed and record their positions
11.Start the timer the moment you let go of both of the carts
12.Stop the timers when the carts travel a set distance, try 1.00 m. If 1.00 m gives you reasonable results, record it under D1 and D2. If not, change the distance and try again.
13.Record the time for the 2 carts on your chart under T1 and T2. Complete 3 trials and average the values.
14.Add another kg mass on cart 2 and repeat the procedure.

Analysis
Compare the total momentum of the system before and after the explosion. To calculate the percent error, take the difference in the momenta and divide by the average magnitudes of the momenta. Show your work. Include units.

Conclusion
Does the data support your hypothesis/background theory? How close is it?

Sources of Uncertainty
How do you explain your deviation from theory? What data supports your claims?

Collisions Lab

Objective:
To explore the conservation of momentum and kinetic energy in an inelastic collision, elastic collision and an explosion.

Hypothesis/Background Theory:
Momentum is conserved in a closed, isolated system. Total energy is always conserved. Kinetic energy is conserved in a perfectly elastic collision. Is the system likely to be isolated? Elastic?
$p=mv$ $E_k = ½ mv^2$

Procedure:
Gliders – The gliders have a card taped to them to start the photogate timers and are on an airtrack to reduce friction.

Inelastic collision

15. Measure the length of the card on the gliders
16. Measure the mass of the gliders along with the paper using an electronic balance
17. Set the timers to zero by pressing clear on the timer. If required, press menu and set the timer to elastic collision.
18. Place the lighter glider on the air track in between the 2 timers.
19. Place the heavier glider on one end of the air track, and make sure that the pointed end is pointed toward the lighter glider, and that the spring end of the lighter glider is facing away from the heavier glider
20. Turn on the vacuum and push the yellow glider toward the red glider
21. Make sure that the two gliders stick together after the collision and move together toward the other end
22. Record the data from the two timers after the gliders have passed the second timer on to your chart. Remember, A and B refer to the photogate, not the glider. If the glider is not moving, record that it is "stationary".
23. Calculate the velocities by dividing the length of the card by the average time.
24. Determine momentum and kinetic energy before and after the collision.

Elastic collision

Use the same gliders, but this time place the gliders so that the end with spring is facing each other on the air track and place the lager glider between the photogates.
Push the smaller glider so that after collision, it will bounce back and pass the first timer, therefore the first photogate will have two different times.
Record the data on your second chart.
Remember that the velocity of the smaller glider is negative when it bounces back.
Determine momentum and kinetic energy before and after the collision.

Data:
Inelastic
Mass of Cart A____________ Mass of Cart B__________________

length of card on Cart A___________ length of card on Cart B______________

Trial	1	2	3	Avg
Time for Cart A before				
Time for Cart A after				
Time for Cart B after (it is not moving before)				

Elastic
Mass of Cart A____________ Mass of Cart B__________________

length of card on Cart A___________ length of card on Cart B______________

Trial	1	2	3	Avg
Time for Cart A before				
Time for Cart A after				
Time for Cart B after (it is not moving before)				

Analysis
Determine the velocities using d/t and calculate the total momentum and kinetic energy of the objects before and after the collision. Remember, momentum is a vector so the cart moving back will have a negative momentum but positive kinetic energy. Determine the % momentum and % kinetic energy lost or gained (difference/originalx100%). Show your work. Include units in your steps.

Conclusion
Does the data support your hypothesis/background theory? How close is it?

Sources of Uncertainty
How do you explain your deviations? What data supports your claims? (Are momentum and kinetic energy always lost? By the same amount? Why?)

The Pinhole Camera

This device was originally called a "camera obscura", when it was invented in the 16th century. It consists of a light-proof box with a pinhole in one end and a screen of frosted glass or tracing paper at the other end. An image is formed on the screen by light travelling in straight lines from an object to the screen. It is easier to see the image on the screen if external light is excluded by shielding the outside of the box with a dark cloth or other covering.

Purpose: To see how an image is formed in a pinhole camera.

Materials: pinhole camera, light source (e.g. showcase lamp)

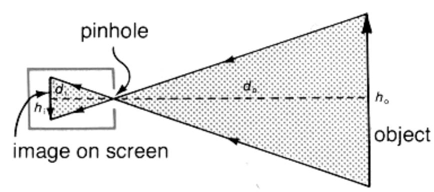
Procedure:

25.Point your camera at the lighted source. This is the object.
26.Look at the image in your camera. Is it larger or smaller than the object? Is it erect or inverted, in comparison with the object? This aspect of an image is called its attitude.
27.Move the camera closer to the lighted object. Does the size of the image or its attitude change?

Questions:

1.From what part of the object does the light at the top of the image originate? From what parts of the object does the light at the middle and bottom of the image originate?
2.If you increase the distance of the camera from the object, what effect does this have on the size and attitude of the image? What is the effect of decreasing the distance?
3.Is the image's attitude erect or inverted throughout the experiment?
4.What property of light, related to transmission, is demonstrated in the simple camera?

Since light travels in straight lines, the rays of light from various parts of the object travel in straight lines through the pinhole and together form an inverted image on the screen. The image is usually smaller than the object. If a line is drawn through the pinhole and perpendicular to both the image and the object, it can be shown by similar triangles that:



The formation of an image in a pinhole camera

$$\frac{\text{height of image}}{\text{height of object}} = \frac{\text{distance of image from pinhole}}{\text{distance of object from pinhole}}$$

The magnification equation is then: $h_i/h_o = d_i/d_o$

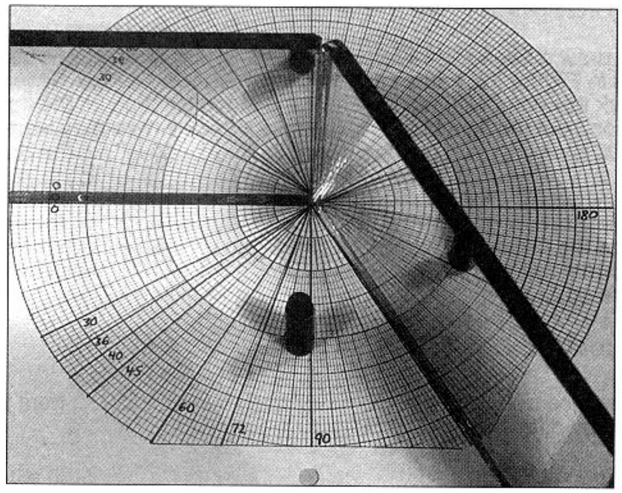
e.g. Calculate the size of the image of a tree that is 8.0 m high and 8- m from a pinhole camera that is 20 cm long.

$h_i/h_o = d_i/d_o \quad h_i = (d_i/d_o)h_o = (0.20\text{ m}/80\text{ m})\ (8.0\text{ m}) = 0.020\text{ m or } 2.0\text{ cm}$

<u>Multiple Images</u>

Purpose: To investigate multiple images in pairs of plane mirrors

Procedure:



1.Arrange two flat mirrors at an angle of 120°. Place a small object such as a rubber stopper approximately 10 cm in front of the mirrors. Look into the mirrors and count the number of images you see. How many images do you see when the mirrors are at 180°? Gradually decrease the angle between the mirrors and watch what happens to the number of images.

2.To investigate the relationship between the number of images and the angle between the mirrors quantitatively, try setting your mirrors at each of the angles in Table 1. In each trial, keep your head still to avoid counting the same image twice by mistake and count the number of images carefully. Copy the table into our notebook and record your results. Be sure to compare notes with other students.

3.Look at the data. Can you figure out a simple rule which will allow you to predict how many images you will see if the mirrors are set at any of these angles? HINT: there are 360° in a circle.

4.If you think you have the rule figured out, predict how many images you will see if you set the mirrors at these angles: a) 30° b) 24° c) 20° d) 0°. (to check out the 0° setting, set the mirrors at 0°, then separate them, keeping them parallel with one another).

Table 1

Angle between Mirrors	Number of Images
180°	
120°	
90°	
72°	
60°	
45°	
40°	
36°	

Questions:

1.What is the rule for predicting how many images you will see if you arrange two mirrors at any angle?

2.You wish to make a kaleidoscope toy with which you will see the same pattern repeated four times (including the object). What angle should you arrange the two long, plane mirrors inside the tube of the kaleidoscope?

Exercises:

1.Why is the image you see in a plane mirror not considered a real image?

2.A child runs towards a mirror at 1.5 m/s. what speed does her image appear to be approaching her?

3.How would you arrange three plane mirrors so that any beam of light striking them will reflect back on itself no matter what angle it strikes the mirrors? This technique was used when placing a reflector on the moon to reflect a laser beam from the earth to the moon and back to the earth. Of what use would such a combination of laser and mirrors be?

4.How many images of yourself will you see if you look into a pair of hinged mirrors forming these angles?

a) 60^o b) 45^o c) 15^o d) 10^o e) 1^o

5.You are 180 cm tall. What is the shortest mirror you can use if you want see our whole beautiful self? Use a diagram to illustrate your answer. Will it matter how far you stand from the mirror?

6.Why is AMBULANCE written in the wrong way on the front of a vehicle?

Refraction

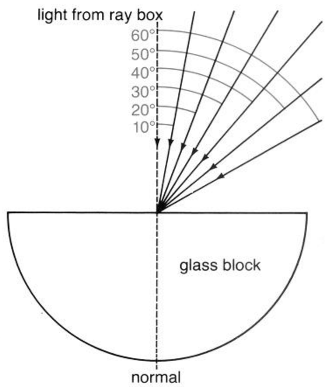
Procedure:

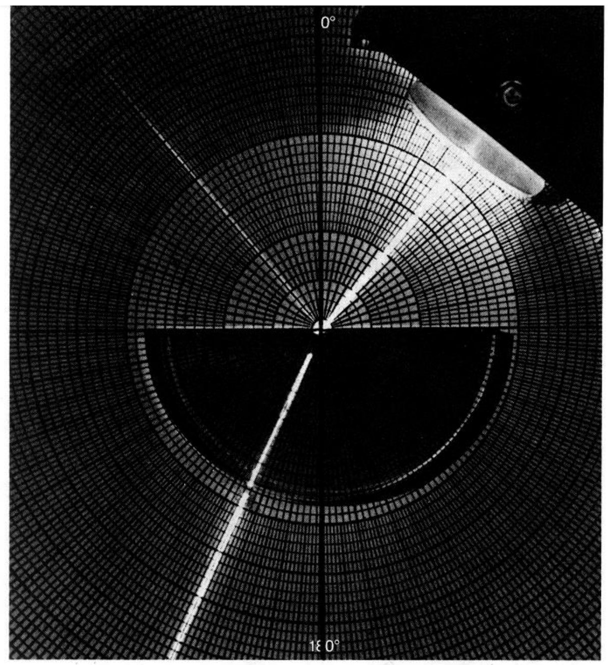
1) Pin a page of polar graph paper to a cardboard base.
2) Pour water into a semicircular plastic dish until it is about three quarters full.
3) Place the flat side of the dish at the centre of the graph paper along one axis.
4) Place a pin at the centre of the graph.
5) Place a pin on the graph paper where you can read the angle.
6) Look at the pin from the other side of the pan through the water. Line up the pin at the centre of the graph with the pin on the other side of the pan and place a pin on that line near your eye.
7) The pin on the far side of the pan is the source of the light ray entering your eye, therefore it will give you the incident angle. Record the angle of incidence.
8) The pin near your eye shows the direction of the refracted ray. Record the angle of refraction.
9) Repeat the process for at least 10 data points. What are the largest values of each angle that you can still see through the dish?.
10) Calculate the sine of all the angles.
11) Graph the incident angle against the refracted angle. Draw a smooth curve through the data.
12) Graph the sine of the incident angle against the sine of the refracted angle.

<u>Refraction of Light by Water</u>

Purpose: To observe how is light refracted when it passes from air into water and develop Snell's Law.

Materials: ray box (with single slit baffle), semi-circular Petri dish filled with water, polar coordinate graph paper.





Procedure:

1.Fill the Petri dish about ½ full of water and place it on the polar coordinate paper, as illustrated, Note that the 0°-180° line acts as a normal and passes through the centre of the flat surface.
2.Direct a single ray of light at the flat surface of the water, along the normal, Measure the angle of refraction, and record it in your notebook in a chart, as illustrated.

Observation	Angle of incidence	Angle of refraction	sin *i*	sin *R*	$\frac{\sin i}{\sin R}$
1	0°				
2	10°				
3	20°				
4	30°				

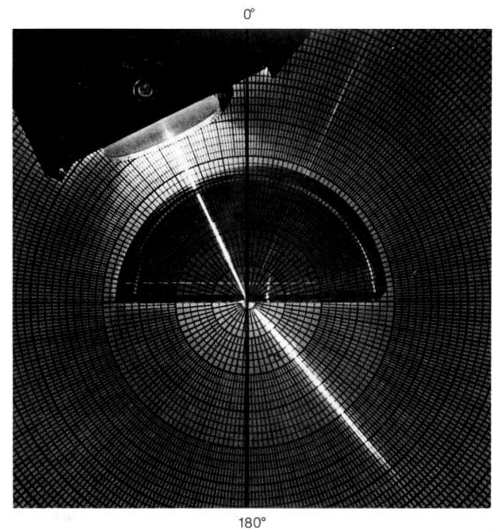
3.Repeat the procedure for angles of incidence of 10°, 20°, 40°, 50°, and 60°, recording your observation in the chart.
4.Determine the values of the sines of the angles of incidence and refraction.
5.Calculate the ratio sin i /sin R for each pair of angles.

Questions:

1.When the light travels from air into water with an angle of incidence of 0°, that is along the normal, what happens to it?
2.When light travels from air to water at the angle of incidence greater than 0°, how is it bent in relation to the normal?
3.Where are the incident and refracted rays located in relation to the normal?
4.How does the angle of refraction compare with the angle of incidence in each case?
5.What do you notice about the ratio sin i/sin R for all angles of incidence greater than 0°?
6.If light travels from water into air, how will it bend in relation to the normal?

Refraction of Light – Water into Air

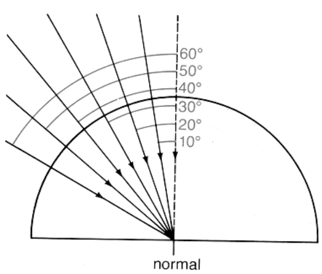
Purpose: To determine how is light refracted when it passes from a medium such as water into a medium that is less dense such as air.



Materials: ray box (with single slit baffle)
semi-circular Petri dish filled with water, polar co-ordinate paper.

Procedure:

1.Fill the Petri dish about ½ full of water and place it on the polar coordinate graph paper as illustrated. Note that the 0^o –180^o line acts as a normal and that it goes through the centre of the flat surface.
2.Direct a single ray of light at the curved surface of the Petri dish along the normal. Measure the angle of refraction in air.



3.Repeat the procedure for angles of incidence in water of 10^o, 20^o, 40^o, 50^o, and 60^o, recording your observations in a suitable chart (see illustration). Be sure to use the "comments" column for any additional observations.
4.Determine the sines of the angles of incidence and refraction, and calculate the ratio sin i/sin R for each pair of angles.

	Angle of incidence	Angle of refraction	sin *i*	sin *R*	sin *i*/sin *R*	Comments
1	0°	0°	0	0	undefined	no refraction
2	10°					
3	20°					
4	30°					

Questions:

1.How was the light refracted when the angle of incidence was 0^o?
2.When light travels from water to air at an angle other than 0^o, how is it bent in relation to the normal?
3.Which angle is always the greater, the angle of incidence or the angle of refraction?
4.Where are the incident and refracted rays located in relation to the normal?
5.What do you notice about the ratio sin sin i/sin R for ***most*** of the angles of incidence greater than 0^o?
6.What is the relationship between the index of refraction for light travelling from water into air and the index of refraction for light travelling from air into water?
7.What other phenomenon occurs increasingly as the angle of incidence increases?
8.Above 50^o, what happens to all the light once it reaches the boundary between the water and the air?
9.At what angle of incidence is the angle of refraction 90^o? Determine the answer experimentally.

Geometric Optics Lab
Lenses, Telescopes, Single Slit, Diffraction Grating

Part 1 – Lenses

Procedure:

1. Get 3 lenses, one concave and two convex of different focal lengths. How can you tell?
2. Look through the lenses and write down what you see when you look
a) across the room b) when you place the lens on writing and lift it
3. Determine the focal length of the two convex lenses. Use light from a distant source (window?) and measure the distance to the image observed on paper.
4. Get a light bulb, ruler, 2 lens holders, 2 ruler stands. Once everyone is ready we can turn out the lights.
5. Put one of the convex lenses into a holder, put it on the metre stick with the light at one end and move a piece of paper until the image is focused. Measure do, di and hi. 6. Move the lens and repeat for 5 different values of do. Copy out this table:

Focal length of lens 1:_____ lens2:_____ h_o:______(size of the filment)

do(cm)	di(cm)	hi(cm)	$\frac{-d_i}{d_o}$	$\frac{h_i}{h_o}$	$\frac{1}{\frac{1}{d_o}+\frac{1}{d_i}}$

Pick one set of data to draw a scale ray diagram. Compare the value of di and hi from the diagram to that from the table and from lens maker's equation.

Part 2, Telescope:

1. Mount the convex lens with the longer focal length at one end of the metre stick. This is the objective lens of your telescope.

2. Attach the second lens on the metre stick. This is the eyepiece of your telescope.

3. While looking through the eyepiece, move the objective lens towards your eyepiece until an object at the other end of the room is in focus.

4. Point the telescope towards the ruled lines (which should be on the far side of the lab) and adjust the position of the eyepiece until the lines can be seen clearly.

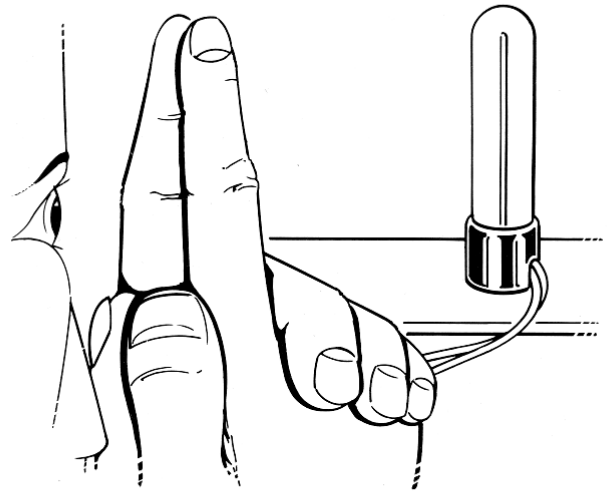
5. Look through the telescope with one eye and look directly at the lines with the other (unaided) eye. Count how many lines, as viewed directly, lie between two adjacent lines as seen through the telescope. This number is a estimate of the magnification produced by the telescope.
6. Compare your magnification to the ratio of the focal lengths.

Diffraction and Interference

Part 3, single slit

Procedure:

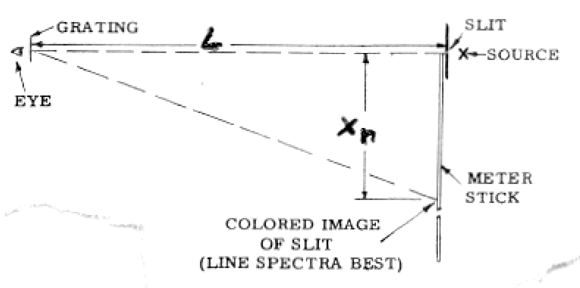
1. Look at the tall light through a small space between your fingers.



What do you notice as you move your fingers closer together and further apart?

Part 4 Diffraction grating (multi slit)

Theory: $n\lambda/d = \sin\theta = x/L$



where: d = separation of lines/slits (m)

λ = wavelength of the light (m)

L = perpendicular distance from the grating to the lamp (m)

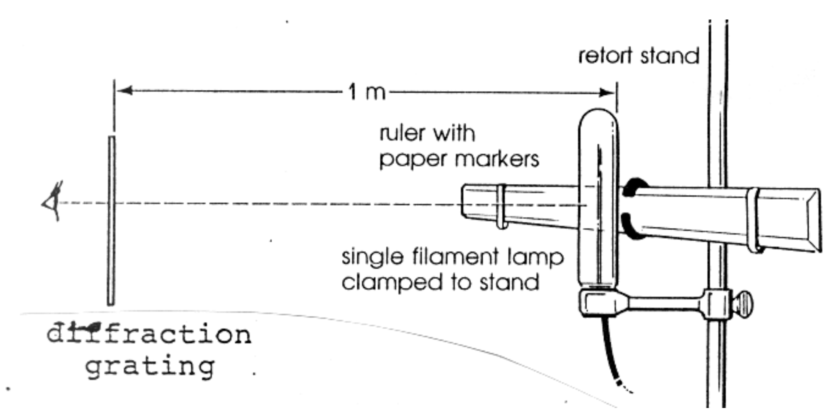
x = distance to the nth nodal line (m)

n = number of nodal line

1.Look at the light through the diffraction grating marked "530 lines/mm". What is the distance between each line, d if there are 530 lines every mm? Turn it so you see colours to the side, not up/down.

2.Adjust your distance to the light to 1.0m and have your partner hold the metre stick so you can measure the distance from the light to the centre of each colour you see to the side. Which colours are farthest from the light?

3.Calculate the wavelengths of each colour you can distinguish.



4.Look at the light using the other diffraction grating (not labeled). Measure the distance to the centre of the red band for the first and second rainbow. Calculate the separation on this grating by comparing the distance to red with that you measured using the first grating with the known d.

Write a formal lab report with purpose, hypothesis (4 parts), procedure (just write refer to sheet), observations, analysis, conclusion(4 parts) and sources of uncertainty.

Colour Theory

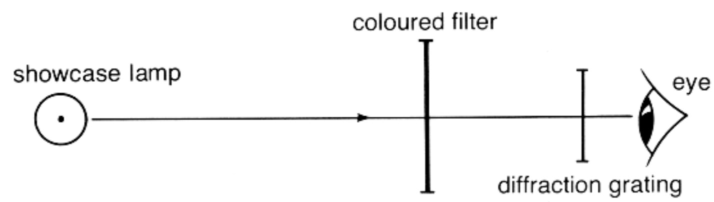
Purpose: To determine what colours are transmitted by cellophane filters. To combine light that has passed through coloured filters onto a screen and observe what colours are produced.

Materials: 3 ray boxes, coloured cellophane, showcase lamp, diffraction grating, white paper (screen).

Procedure:

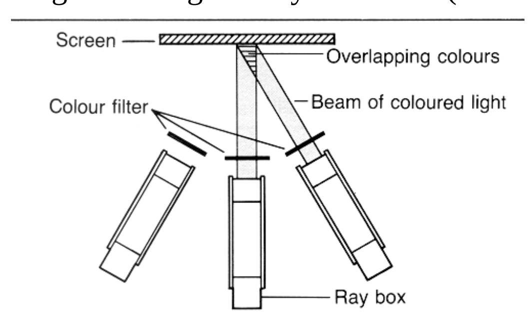
Part 1 - Overlapping coloured filters

1.Place a coloured filter around the showcase lamp and use the diffraction grating to determine what colours are transmitted.
Record your results in an appropriate data table.
2.Repeat procedure 1 for different colours of cellophane.
3.Combine the filters in groups of two and again record which colours you see.



Part 2 - Combining Coloured Lights

Arrange the three ray boxes so that their beams of light converge onto your screen (white paper).
Using the red, blue and green filters, first combine the colours in groups of two and describe the colour that is produced on the screen where they overlap.
Combine light using all three coloured filters and all three ray boxes and describe the colour produced on the screen where they overlap.



Questions:

1.How do the colours of light passed by each individual filter in part 1 compare to what is predicted by Subtractive Colour Theory?
2.How do the colours produced by combining light of different colours in Part 2 compare to those predicted by Additive Colour Theory?

Relativity : Analyzing the Twin Paradox

In 1905, Albert Einstein predicted that high speed travel could alter the rate at which one ages. This can be illustrated by examining identical twins, one which takes such a high speed trip while the other remains at home. After a period of time the traveling twin returns home to discover that his stay-at home twin seems to have aged more rapidly than himself. The following activity should enable you to appreciate why there may be a difference in their biological clocks.

Problem

Suppose you send your identical twin to a star 10 light years away at a speed $v = 0.9c$ (90% the speed of light). Neglect times for acceleration, turn around etc. Round all numbers to the 3rd decimal place.
(Several answers are provided to assist you)

(i) Outward Journey

1. Calculate how long it takes an object with $v = 0.9c$ to travel 10 light years. _______ years
2. Therefore your clock will have advanced _______ years when your twin reaches the star.
3. Will you see your twin at the star the moment he arrives? _______
(Remember the star is 10 light years away).
4. How long will it take the light from the star and your twin to return to earth? ______years
5. What will your clock say just when you see your twin arrive at the star? _______ years.
Ans : 21.111 years
6. Calculate $\sqrt{(1-v^2/c^2)}$ for $v = 0.9c$ _________
7. Refer to (2) and (6) and calculate how much your twins clock will have advanced just as he reaches the star. _______ years.
8. Therefore when you see your twin arrive at the star you see his clock reads ______years
9. If your clock advanced 20 min. and a friend's clock who thinks he is right advanced 10 min. Then your friend would think your clock is running _______ times too fast/slow.
10. Refer to (5) and (8) and calculate how many times faster your clock is compared to your twin's on the outward journey. ______
11. Refer to (2) which tells you how long on your clock it took your twin to get to the star even though you haven't seen this yet. Now remember it takes 10 years for light to travel from the earth to the star. If your twin were to look at your clock just when he reached the star what would he read? _________ years. **Ans : 1.111 years**
12. Now refer to (7) and (11) and calculate how many times faster the twin sees his clock advancing compared to yours __________. Compare this answer to (10)
13. On the outward journey do both you and your twin see each other's clocks running slower?
____
14. Recalling the Lorentz contraction calculate how far 10 light years would appear to be contracted by a ship moving relative to this distance at a speed $v = 0.9c$ ________ lt years.
15. If $v = 0.9c$ how long would it take to travel the distance in (14)? _____ years. Compare your answer to (7)

(ii) Return Journey

16. How long will it take the ship at $v= 0.9c$ to return to the earth? ______ years.

17. Refer to (1) and (16). How long has the twin been gone? _______ years.
18. How much have you aged? _________years.
19. When you first saw the ship at the star what did your clock say?
__________ years. Refer to (5).
20. Now that the twin is back what does your clock say? _________ Refer to (17).
21. How long do you record the time for only the return journey? ________years
22. How much will yourtwins clock advance on the return journey. ________years Refer to (7)
23. Refer to (21) and (22) and calculate how many times faster you see your twins clock advance on the return trip. **Ans 4.360**
24. Refer to (11) and (20) and calculate how much time your twin sees elapses on your clock on the return trip. **Ans 21.111 years**
25. Refer to (22) and (24) and calculate how many times faster your twin sees your clock running faster than his. _________ Compare to (23)
26. How many of your years was your twins clock running slower? __________
27. How many of your years was your twins clock running faster? __________
28. How many of your twins years was your clock running slower? __________
29. How many of your twins years was your clock running faster? __________
30. How much did you age again? __________
31. How much did your twin age? __________
32. Divide (31) into (30). __________
33. Who did the accelerating? ______

Note : The accelerating twin is the one that experiences time dilation. It was this factor that resolved the problem of which twin aged more slowly and hence removed the problem as a paradox.

Relativity Lab Answers

1. 11.111	**7.** 4.844	**13.** Yes	**19.** 21.111	**25.** 4.358	**31.** 9.688
2. 11.111	**8.** 4.844	**14.** 4.36	**20.** 22.222	**26.** 21.111	**32.** 2.294
3. No	**9.** 2, Fast	**15.** 4.844	**21.** 1.111	**27.** 1.111	**33.** Twin
4. 10	**10.** 4.358	**16.** 11.111	**22.** 4.844	**28.** 4.844	
5. 21.111	**11.** 1.111	**17.** 22.222	**23.** 4.360	**29.** 4.844	
6. 0.436	**12.** 4.36	**18.** 22.222	**24.** 21.111	**30.** 22.222	

SPEED, ENERGY, AND MASS -THE ULTIMATE SPEED

Special Relativity Experiment

Introduction:

Newton's Laws of Motion tell us that a body will accelerate uniformly under the action of a constant unbalanced force. Thus, the speed of a body initially at rest should increase linearly with time. From Newton's Second Law, where $F=ma=(m\Delta v/\Delta t)$, we see that the change in speed is $\Delta v = (Fm/\Delta t)$. The longer the force is applied, the longer the body accelerates at a uniform rate and so the faster it goes. There is no upper speed limit in Newtonian mechanics. As long as an unbalanced force acts, the body accelerates at a uniform rate even beyond the speed of light.

The situation is not the same in Einstein's relativity. Here, there is an upper limit to speed, and that is the speed of light. A constant force acting over time will not produce uniform acceleration when speeds near that of light are approached. Instead, acceleration decreases as relative mass increases and the speed approaches the limit of the speed of light.

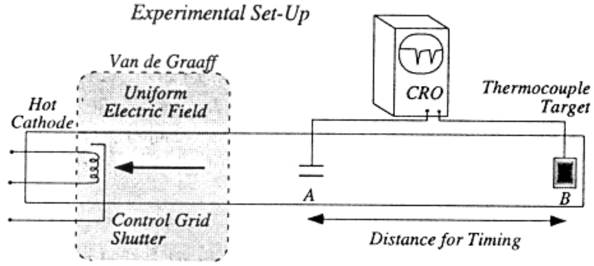
Newton's Formula for Acceleration (1686)	*Einstein's Formula for Acceleration (1905)*
$a=\frac{F}{m}$ where $m \equiv m_0$	$a=\frac{F}{m_0}\left(1-\frac{v^2}{c^2}\right)^{3/2}$

Einstein's equations approximate Newtonian equations when speeds are low compared to the speed of light. The following experimental exercise will investigate the energy associated with fast moving electrons. In this assignment you will study actual data from highly accelerated electrons and compare actual speeds with Newtonian predictions. The evidence here will then support Einstein's theory.

The Ultimate Speed

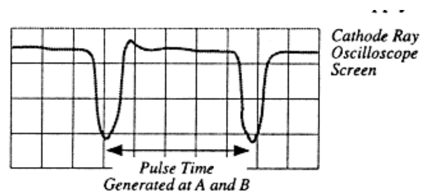
Electrons are relatively light bodies and easily accelerated to very fast speeds. For example, an electron accelerated through a potential difference of 2500 volts in a cathode-ray tube will be moving at a speed of about one-tenth of the speed of light. The effect is much more dramatically illustrated if we can use accelerating potential of about a million volts. A Van de Graaff accelerator at the Massachusetts Institute of Technology was used as a source of high voltage for an experiment of this type. The general arrangement is shown below.

Experimental Set-Up



Electrons from a hot cathode are accelerated by a large difference in potential maintained by the Van de Graaff. They emerge from the Van de Graaff into a long tube which has no electric field in it. The electrons move down this tube without accelerating, and their speed is found by timing their flight time from *A* to *B*. For accurate measurement it is essential that the electrons be emitted in bursts whose duration is short compared with the time of flight. A shutter that will open for extremely short time interval, about 3×10^{-9}s, has been made by placing a grid close to

the cathode and keeping it charged negatively until we wish to emit a burst of electrons. We then apply a sharp pulse of positive charge to the grid, and a short burst of electrons will be released. The time of flight is indicated by an oscilloscope; when the burst of electrons pass A and B, electrical pulses are generated and these appear as spikes on the oscilloscope face.



All the precautions taken in determining the speed of the electrons assure its correctness. But can we be equally sure of the correctness of the values of kinetic energy of the electrons? The kinetic energy of a particle which starts from rest equals the work done on it, that is, the force times distance. The distance is easily measurable. If the speed of the electron would remain low, we could calculate the force by dividing the potential difference between the two terminals of the Van de Graaff by the distance between them: $F = qV/d$ and so $E_k = (q\,V/d)d = q\,v$. Does this relation hold also when the electron moves at speeds close to the speed of light? To check up on this point, an aluminum disc containing a thermocouple was placed near *B*. The kinetic energy of the impinging electrons was converted into thermal energy of the disc, and the rise in temperature was measured. From the rise in temperature and the number of electrons hitting the cylinder, the kinetic energy of each electron was calculated and found to agree with the potential energy.

The Experiment

Kinetic Energy $E_k\,/\,MeV$ $\pm 0.2\,MeV$	Flight Time $t/10^{-8}s$ $\pm 0.05\times10^{-8}\,s$
0.5	3.23
1.0	3.08
1.5	2.94
4.5	2.84
15.0	2.80

The experimental results for accelerating electrons are given here. The kinetic energy is calculated in *mega-electron-volts,* and the time is in units of 10^{-8}s. These time intervals are for the known distance, (l = 8.40 m). You will need to copy the given data and add columns for *Speed* in *m/s*, *Speed Squared* in m^2/s^2, and for the *Ratio of Speed with the Speed of Light, v/c.*

Graph One

You are to construct a graph of the Square of Speed in m^2/s^2 against Kinetic Energy in *MeV.* Plot two lines. First, plot the theoretical line of speed squared in Newtonian mechanics against kinetic energy; assume energy values of 0 *MeV*, 0.1 *MeV,* 0.2 *MeV*, 0.3 *MeV*, and 0.4 *MeV* only. Here is an example of how to calculate the Newtonian value:

$$E_k = \frac{1}{2}m_e v^2 \;\rightarrow\; v^2 = \frac{2E_k}{m_e}$$

$$v^2 = \frac{(2)(0.4MeV)(10^6/M)(1.6\times10^{-19}J/eV)}{9.1\times10^{-31}kg} \approx 14.1\times10^{16}m^2s^{-2}$$

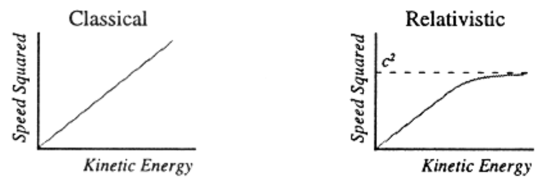
Second, on the same axes, plot the experimental values for **Speed Squared** and **Kinetic Energy**. Be sure to make your graph as large as possible.

In classical Newtonian mechanics, kinetic energy is $E_k = 1/2(mv^2)$, and this predicts that speed squared should be proportional to the kinetic energy, $v^2 \propto E_k$. A graph of speed squared against kinetic energy should then be a straight line. When you plot the experimental values you will find that this relationship does not hold. Experiments involving speeds close to the speed of light do not disprove the laws of classical

physics; they only point out that these laws cannot be simply extrapolated without bounds, but must be modified at high speeds because of the special role played by the speed of light. Comment on what your graph reveals.

Graph Two

Draw a second graph, this time of **Kinetic Energy**, E_k in *MeV*, against the **Ratio of the Electron's Speed to the Speed or Light**, *v/c*. Plot both the experimental values as calculated and the classical Newtonian values. For a better appreciation of the difference, allow the *v/c* scale to go from zero to 1.2. Comment about the experimental result and appreciate how there is a limit to the *v/c* ratio.



Half-Life

By using a large quantity of dice it is possible to determine the half-life for a particular number to appear face-up on the dice as they are consecutively rolled. The experimentally determined half-life can also be compared to a theoretical value determined through calculation.

Materials: dice, large unbreakable container

Procedure:

1.Initially count out a fairly large number of dice (at least 100)
2.Select one of the die numbers to represent a decay.
3.Place all of the dice into the container.
4.Allow a group of students to shake the container and dump all of the dice onto the floor or table-top. Avoid collisions with objects other than the dice themselves.
5.Count and record the number of dice that have "decayed" and "undecayed". Record this as roll number 1.
6.Place the "undecayed" dice back into the container and pass it to another group of students to repeat procedures #4 and #5. Put the "decayed" dice aside.
7.Repeat this process many times (about 20-25) or until all dice have decayed.
8.Plot a graph of the # of undecayed dice against roll number. **Note:** Initially the dice were not rolled but only counted and this is roll number zero.
9.If there is time, repeat procedures 1-8 with many more dice (approximately double)

Analysis:

1.Determine the average half-life of the rolled dice from your graph. Do this by averaging the number of rolls required to reduce the undecayed dice to one-half (the 1^{st} half-life), the number of additional roles required to reduce this half by half (2^{nd} half-life), etc. You should use at least 4 or 5 half-lives in your calculation.
2.Compare the graph shapes and the average half-lives from various experiments that used different numbers of starting dice (if time allows).
3.Compare your most reliable half-life value with the theoretically determined one. Try to estimate a value through reasoning and perhaps trial and error if your mathematics is insufficient. Hint: Logarithms are very useful in the theoretical calculation.